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ABSTRACT

This paper introduces integrated curriculum material for high school physics developed by the Physics Education Research Group (PERG) with the University of Massachusetts and high school teachers. This curriculum is based on an action-oriented constructivist approach. There are six types of materials in the curriculum: (1) student activities; (2) student reader; (3) answers and instructional aids for teachers; (4) assessment items; (5) supplements; and (6) answer sheets. (YDS)

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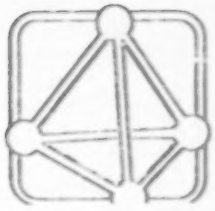

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MINDS-ON PHYSICS: Materials for developing concept-based problem-solving skills in physics

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Introduction. For the past eight years the Physics Education Research Group (PERG) at the University of Massachusetts has been developing a set of integrated curriculum materials for high school physics, called Minds•On Physics (MOP). PERG combines expertise both in cognitive research and in teaching physics at the University level, and we have applied this expertise fully in order to create materials rooted in both research and pedagogy.

Our development strategy is based on well articulated principles of effective knowledge organization, effective problem solving, and effective instructional strategies that are based on educational research findings. The development team includes both PERG staff and high school teachers. The approach to learning physics reflected in the MOP materials emphasizes the role of physics concepts and principles in understanding physics and solving problems. Our approach also stresses the importance of structured knowledge for deep understanding and efficient problem solving.

The project is nearly complete. Five volumes of student activities (and four accompanying Teacher's Guides) have been published by Kendall/Hunt. One more volume of activities and two more Teacher's Guides are planned before Summer 2000. When completed, there will be more than 180 activities to choose from, each one with extensive support materials.

Approach. The MOP approach is ***constructivist***. By this, we mean:

(1) Knowledge is constructed, <u>not</u> transmitted (only information is transmitted).

(2) Prior learning filters all experiences and therefore impacts subsequent learning.

(3) Initial understanding is local, not global.

(4) Building useful knowledge structures requires effort.

Activities are organized to maximize students' attention, motivation, interest, involvement, and success. Our approach is ***action-oriented***, meaning that we encourage little (if any) lecturing by the teacher, and require minimal reading by the student. Instead, activities involve interactions with either a teacher or other students, or personal reflections on prior activities.

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Because knowledge must be structured in order to be useful for understanding and for problem solving, the activities revisit the main ideas (such as Newton's laws and conservation laws) often, and make connections among them to help students integrate their knowledge. Using our activities, students learn not only concepts, principles, equations, operations, and procedures, but also how these are related to each other and to problem situations. Because of this, knowledge is more easily accessible when students analyze physical situations.

Form of Materials. There are 6 major types of materials within the MOP curriculum, each of which is described below. They are: (1) Student Activities, (2) Student Reader, (3) Answers and Instructional Aids for Teachers, (4) Assessment Items, (5) Supplements, and (6) Answer Sheets.

(1) STUDENT ACTIVITIES. The core of the curriculum is an integrated set of activities. Each activity contains the following sections.

Purpose and Expected Outcome. In this section, we tell students the specific concepts, principles, and other ideas that will be raised and addressed during the activity.

Prior Experience / Knowledge Needed. We first list for students the concepts and principles they should be familiar with before attempting the activity. Then, if necessary, we provide additional background information needed to do the activity.

Main Activity. This section contains the specific questions and problems that probe students' understanding and prepare them to make sense out of the ideas.

Reflection. After finishing the main activity, students re-examine their answers to look for patterns. They are also asked to generalize, abstract, and relate concepts to the situations they have studied.

Currently, the entire mechanics portion of the curriculum, containing about 100 activities, has been completed and is contained in the first 3 volumes of activities. We also have completed another 50 or so supplemental activities covering electricity, magnetism, gravitation, circular motion, projectile motion, relative motion, and rotational motion. By Summer 2000, we will have another 30 (or so) activities covering oscillations & waves, fluids (both static and moving), and heat, thermodynamics, basic calorimetry, and entropy. Each activity is designed to be completed in one class hour, although some might take longer based on the depth of coverage desired.

Many of the activities are "hands-on" as well as "minds-on". Our hands-on activities are quite distinct from formal and traditional labs, which tend to be "cookbook" in nature and to involve large amounts of data manipulation and analysis, and time-consuming lab reports.

Most of our hands-on activities are simpler explorations of physical phenomena, with frequent references to the concepts relevant to understanding the phenomena.

(2) STUDENT READER. There is no textbook to accompany the activities. However, there is a terse Reader, averaging about 1 page for each of the earlier activities and about 2 pages for each of the later ones. The intent is that students begin by doing the activities with little or no preparation (from the teacher or from any other source material). Any preparation that might be needed is provided in the *Prior Experience / Knowledge Needed* sections of the activities. The appropriate part of the Reader is designed to be read after the student finishes the corresponding activity (or set of activities), and is intended to summarize and to knit together the ideas and issues raised in the activities. The students can then use the Reader as a resource for activities done later.

(3) ANSWERS & INSTRUCTIONAL AIDS FOR TEACHERS. Answers are an invaluable resource for teachers, especially because many of the activities are challenging even for experienced teachers. At the very least, they allow teachers to see how we think about a situation or problem. Answers always include a short explanation, where the emphasis is on the process of analyzing each question, being aware of one's assumptions, and arriving at an answer consistent with those assumptions.

The approach is challenging as well. The Instructional Aids are our way of communicating the philosophy behind each activity, as well as each set of activities. We explain our goals and our expectations for each activity, and try to give warnings about student difficulties, misunderstandings, and common responses. We also suggest ways to overcome students' difficulties and ways to interpret different patterns of students' responses. The Instructional Aids are intended to prepare teachers in their role as coaches of students' learning.

(4) ASSESSMENT ITEMS. We know that the traditional ways of testing students do little to uncover conceptual difficulties or to measure knowledge of physical laws and principles. New ways of assessing students' progress must necessarily be developed alongside new approaches to teaching. New assessments need to encourage students to focus on those features that are important for deep understanding. Without new assessments, students will remain largely unwilling to abandon formulaic approaches. We provide examples of how new assessments might be structured to probe students' progress with the new approach and to probe their conceptual understanding; these are currently found in the "Probing for Student Understanding" sections of the Answers and Instructional Aids.

(5) SUPPLEMENTS. In the first Teacher's Guide (i.e., *Motion*), there are three supplements to help teachers. The first is a short summary of collaborative group techniques and some references teachers can use to get more information about incorporating group work. The second is a description of (what we call) the "concept-based problem solving" approach to teaching and learning physics, with an emphasis on the cognitive research results that motivate the approach, and the practices that can improve the classroom dynamic. The third

supplement is a comparison of the MOP approach with the National Research Council's (USA) 1996 National Science Education Standards. This comparison should be of particular value to administrators trying to decide if MOP should be adopted in their school systems.

(6) ANSWER SHEETS. For every activity there are customized answer sheets that teachers may reproduce and give to students to do their work on. For instance, when graphs are requested or needed to answer a question, grids are provided on the answer sheets. When students are asked to use a strobe diagram to measure displacements, the same diagram is provided for them to work on. This makes it less likely that students will write in the activities books and makes the activities books completely reuseable.

Style. The MOP materials are designed with the following goals in mind:

(1) *Reveal and address students' misconceptions.* We know that misconceptions are often difficult to dislodge and usually interfere with learning. We believe that the best way to overcome these misunderstandings is for students to uncover and confront them. Thus, our activities involve situations that help students with particular misconceptions to recognize any contradictions arising from their conceptions. We then offer and develop the scientific view as a way for the students to modify their models and resolve the contradictions.

(2) *Emphasize the role of concepts in problem solving.* We know that students usually do not appreciate the usefulness and role of concepts in guiding problem solving. Part of the reason for this is that students often do not become proficient at analyzing problem situations, and are usually successful only when using formulaic approaches. Therefore, we ask students open-ended questions about problem situations, so that they must use concepts to analyze situations.

(3) *Show students how to use concepts and principles to solve problems.* Before assigning problems, we ask students to analyze and reflect upon problem solutions and explanations that we provide. Then, instead of assigning lots of problems, we assign just a few, each of which requires prior conceptual analysis to solve.

(4) *Discourage formulaic approaches to solving problems.* While equations are an important part of any physics curriculum, equations need not be its central focus. Using our activities, students learn alternative ways of solving problems. They learn how a graph or sketch can guide and focus their thinking toward the central features of some problems and thus reveal a relatively simple solution. In some of our activities, simple reasoning or comparisons with known phenomena will yield the result. In Activity 16, for example, students work on problems that are nearly impossible for them to solve using algebra, but that are relatively easily solved using graphs, strobe diagrams, or common sense.

(5) *Promote knowledge structuring and integration.* Most students store knowledge chronologically in the order that the material was taught. They find cumulative exams

difficult because older material becomes inaccessible to them. Structured knowledge is much more easily stored and accessed, making it much more useful for analysis and problem solving. By constantly revisiting important topics in new contexts, our activities require students to integrate knowledge, to increase the number of connections among knowledge elements, and to help students look for connections themselves among ideas and situations.

Special characteristics. MOP materials have a number of features that distinguish them from most traditional physics curricula:

(1) *MOP materials are consonant with findings from many different strands of educational and cognitive research.* These materials incorporate results of misconceptions research; expert–novice studies; studies of the cognitive load associated with different styles of questions; research into the effectiveness of collaborative groups; studies of active-learning strategies; and the effects of meta-communication on the learning process.

(2) *MOP materials are designed using a well articulated cognitive framework for the acquisition, storage, and use of knowledge in problem solving.* Using this framework we have identified numerous beneficial cognitive processes and instructional modes that promote conceptual development.

(3) *MOP curriculum is driven by activities rather than a textbook.* The MOP activities are designed to be used within a cooperative learning format where students work collaboratively to make sense of physics concepts. Students initially explore each concept and principle by working through an activity, rather than by reading a textbook or listening to a lecture. Each activity contains a minimal amount of reading to start students thinking about the relevant ideas. Students try to make sense out of the questions through reflection and through interactions with the teacher and with other students. The activities can generate many new ideas, create lively discussions, and give the teacher a sense of students' progress.

(4) *MOP curriculum incorporates assessment issues.* In order to provide better feedback (to both students and teachers) we provide the teacher with sample assessments to probe for conceptual understanding. For example, some assessments ask students to compare two physical quantities and to explain their answer. Others ask students to divide a set of problems into categories based on how similarly the problems are solved. Students quickly learn that knowing how to analyze physical situations is more useful, more highly rewarded and more highly regarded than knowing how to manipulate equations.

(5) *MOP materials require that teachers play the role of coach rather than dispensers of information.* A teacher who uses our approach spends less time preparing lectures and more time structuring experiences for students. Depending on the assumptions made (by

students), activity questions usually have more than one justifiable answer. Thus, emphasis is placed on intelligent discussion of the questions. In this mode, a teacher serves as a facilitator, counselor, or coach, rather than a lecturer, by turning students' attention to those ideas that will eventually help them reach a satisfactory conclusion.

(6) *MOP materials have been field tested at numerous sites across the country*. More than 20 teachers in 5 states with a total of over 1000 students piloted the MOP materials. We have met frequently with our pilot teachers during the six-year duration of the project. We have also had a small number of resident teachers work with us during summers to help us develop and refine the activities. The MOP teachers have provided us with invaluable feedback over the years.

Content. The topics in the mechanics portion of the MOP curriculum include most topics covered by a majority of high-school physics teachers. If used in their entirety, the mechanics portion would take approximately 3/4ths of the school year to complete. The structure of the mechanics topics is described below.

- MOTION / KINEMATICS (36 Activities). Students start their study of motion by building connections between everyday experiences and physical descriptions of motion. Motions are represented and analyzed in a variety of ways: graphs, strobe diagrams, verbal descriptions, and mathematical descriptions. Particular emphasis is placed on the relationships between types of graphs (such as velocity–time and position–time graphs), so that students can relate one type of graph to another. The activities stress the many different ways to solve kinematics problems, and the need to consider a variety of representations before actually solving a problem.

- INTERACTIONS / DYNAMICS (35 Activities, including 5 on vectors). Forces are presented as being the direct result of interactions between objects. In our activities, students are exposed to a wide range of forces. "Real-life" situations provide varied contexts in which students learn to identify forces. Qualitative activities focus on predicting the behavior of objects using Newton's laws. Free-body diagrams and vector representations provide multiple tools for analysis.

- CONSERVATION LAWS / MOMENTUM & ENERGY (25 Activities). Conservation of momentum and conservation of energy are developed as examples of conservation laws. Students learn to use these conservation principles to predict the behavior of objects and to provide a conceptual analysis of problem situations. Connections are established between conservation of momentum and energy and Newton's laws.

- CONCEPT-BASED PROBLEM SOLVING (7 Activities). These activities help students synthesize, integrate, and organize knowledge. They highlight the major principles and

procedures used throughout the previous activities, and encourage the flexible application of physics knowledge to solve problems.

These 102 activities constitute the "core" of the MOP curriculum. By the Summer of 2000, there will be additional supplemental topics (in three separate volumes). The main thrust of the supplemental activities will be to demonstrate how the major ideas in the core curriculum apply across a wide range of phenomena. Below is a list of the supplemental volumes with a description of each.

- FUNDAMENTAL FORCES & FIELDS (29 activities). Students will model the electric, magnetic, and gravitational interactions, and learn to apply their models to a variety of situations. Students will learn the idea of a field to explain gravitation, electricity and magnetism. Students will wrap up this volume by integrating the ideas learned with prior knowledge learned in the core curriculum.

- COMPLEX SYSTEMS (approximately 30 activities). Systems that involve the aggregate behavior of large numbers of particles such as waves on a string, objects floating in fluids, and heat engines are often taught under the separate subjects of Heat & Thermodynamics, Oscillations & Waves, and Fluids. However, because each of these systems can be analyzed using Newton's laws and conservation principles, they can effectively be integrated under the topic of complex systems.

- ADVANCED TOPICS IN MECHANICS (23 activities). We will apply Newton's laws and conservation laws to objects undergoing circular motion and projectile motion. We will also expand students' understanding of relative motion (in both one and two dimensions) and rotational motion.

Evaluation. The materials and their implementation at various test sites have been extensively studied by Prof. Allan Feldman (University of Massachusetts School of Education) and his team of graduate students. They used questionnaires, site visits, video taped classes, and interviews to determine what effect the MOP materials had on students and teachers, and how this compared to what the developers intended.

(1) When the MOP materials were used as recommended, students...

... did acquire expert-like problem-solving abilities, not usually accessible with traditional curricula;

... were more self-aware than students who used MOP materials only occasionally; and

... sometimes got frustrated, especially when they insisted on knowing the "right" answer to every question.

(2) Teachers using MOP...

... often learned physics they hadn't learned before;

... were more aware of students' conceptions, ideas, knowledge, attitudes, etc.;

... often used collaborative learning for the first time;

... were exposed to educational research results for the first time;

... sometimes did not share developers' goals;

... sometimes struggled due to limitations in physics knowledge, teaching expertise, and/or circumstance; and

... sometimes perceived no difference between what they were doing and what was expected of them.

Most teachers did not change their instructional practices very much during their involvement with the project. However, there was change, and it was slow, with larger changes associated with longer involvement with the developers. This suggests that teachers need intensive and protracted support in order to change their instructional approaches.

Information. For more information about the Minds•On Physics project, please contact Bill Leonard at 413 / 545–0442 or wjleonard@physics.umass.edu, or visit the UMass PERG website at http://umperg.physics.umass.edu/. For sample activities, go first to the "Projects" hyperlink (within the UMass PERG site), then go to "Minds•On Physics" and finally to "MOP Samples". Or go directly to http://umperg.physics.umass.edu/projects/MindsOnPhysics/MOPSamples.html.

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